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Analysis of Track Responses to Train Braking

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INTRODUCTION

Implementation of new track concepts within the live rail-network require evaluation of mechanical infrastructure responses to expected train-loads. As braking forces are part of such an assessment, the current work deals with analysis of railway track reactions for this load case. This can be critical for design, especially when advancements in braking technology as well as in track-forms, e.g., asphalt overlayment solutions, are evaluated. In the latter case, concrete sleepers rest on an asphalt pavement surface - possibly without crib or shoulder ballast. This implies that longitudinal loads at the interface of sleeper-substructure are primarily resisted by the available sliding capacity at the sleeper base; which may be inferior when contrasted against traditional ballasted track where crib and shoulder ballast additionally contribute to the sliding resistance (*1*).

Determination of track responses to train braking requires consideration of the impacts of both vertical and longitudinal vehicular loads. In railway-design, models for the former category are quite well recognized, but limited literature about the latter has been published. Numerical studies were carried out by Van (*2*) to determine the rail reactions due to braking loads. However, the interaction between vertical and longitudinal directions was not accounted for, and response at individual sleepers was not investigated. Finite element analyses were carried out by Zhang et al. (*3*) to study the friction demand at rail-rail pad interface during train acceleration. It was reported that longitudinal forces at these interfaces were negligible in front of the wheel and that the load was mainly carried by about five sleepers located behind the wheel. However, the non-symmetric distribution of the responses was not physically explained.

Subsequently, the objective of this study was to build up a model capable of analyzing railway track response to braking loads, accommodating both traditional and modern braking systems. The purpose was to provide a tool for (i) determining the axial rail stresses, (ii) ascertaining the number of participating sleepers and their influence in transmitting braking loads to the substructure, and (iii) portraying the friction demand at the sleeper-substructure level. An analytic framework was pursued for the development of the model in order to provide useful closed-form solutions.

METHODOLOGY

A new response-model for railway tracks was developed, focusing on loads generated during vehicular braking. In the proposed model, the rail was considered as an infinite homogenous Euler-Bernoulli beam; the weight per unit length of the beam comprised of the unit weight of the rail and the distributed sleeper weight considering one-half of it. The beam was continuously supported along the neutral axis by an orthogonal Winkler type foundation consisting of springs both in vertical and longitudinal directions at right angles to each other. These springs represent the collective support offered to the rail by all underlying track components.

A coordinate origin was placed at the location corresponding to a randomly chosen sleeper being addressed in the braking zone. Closed-form expressions were derived, as a function of the load position from the origin, for calculating vertical and longitudinal responses generated by a braking axle situation. These responses included: (i) beam vertical displacement, (ii) vertical force at the base of a random sleeper, (iii) longitudinal beam displacement, (iv) longitudinal force at the base of a sleeper, and (v) friction demand at the base of a sleeper. The latter entity represents the required resistance at the sleeper base to ensure no-slip conditions during a braking event. Closed form expressions were also derived to address modern braking technologies, in which the braking effort does not depend exclusively on a wheel clamping mechanism but rather applied over a certain rail length.

FINDINGS

For demonstrating the formulation capabilities, the analytical framework was parametrically investigated to analyze the braking event of a single train axle. The main findings from this investigation were: (i) peak longitudinal rail stress does not depend on the underlying support condition; however its distribution along the beam length is a function of the latter, (ii) longitudinal track responses impact a much larger zone in comparison to vertical responses, (iii) peak friction demand escalates with an increase in the spring constants, and (iv) peak friction demand is too high to be solely met with a standard sleeper weight; nevertheless, it can be within an acceptably low range when employing a heavier sleeper type. It was also possible to estimate the load positions where the friction demand at the base of a sleeper reached a maximum value.

Next, the model was demonstrated for a full train considering representative sets of vertical and longitudinal loads simulating a predefined series of axles. The train chosen for this purpose was Thalys HST (*4*), having a length of approximately 200 m and 26 axles. The vertical axle loads were each 170 kN and longitudinal loads were assumed 25% of the vertical loads, i.e., 42.5 kN each. The spring constants in vertical and longitudinal directions were 20 MPa and 5 MPa respectively. The properties of the beam were taken to be that of UIC 60 rail section and the concrete sleeper type chosen was a standard one having a weight of 290 kg kept at a spacing of 600 mm.

Figure 1 illustrates the main outcomes of this demonstration. It consists of four charts depicting the mechanical responses generated in the rail and at a sleeper base during the event of braking of the train. The abscissa in all charts is identical, representing the offset distance from the rear axle of the Thalys HST train to the evaluation point. Figure 1a depicts the variation of vertical force at a sleeper base, Figure 1b shows the change in longitudinal force at a sleeper base, Figure 1c displays the longitudinal beam stress, and Figure 1d presents the friction demand at a sleeper base (i.e., the ratio between longitudinal and vertical forces). Also included in Figure 1 (dashed lines) are the corresponding peak calculation results for a braking event of a single train axle.

Overall, it can be observed that responses in the longitudinal direction (Figures 1b and 1c), as well as peak friction demand (Figure 1d) increased considerably compared to the single axle case while vertical track responses (Figure 1a) remained almost similar. This shows that load interaction between axles is very prominent in the longitudinal direction compared to the vertical direction. Both demonstrations were performed considering a traditional braking mechanism, wherein the wheels are decelerating due to clamping.

CONCLUSION

The findings of the study can be summed up to arrive at two important conclusions: (i) track responses, generated by braking of a full train, cannot be derived from a single axle analysis as peak responses resulting from longitudinal loads are generally much larger than a single axle case, and (ii) a non-standard/heavier sleeper type may be essential in track-forms where the sliding resistance at the sleeper base is solely dependent on friction. In forthcoming studies, the model can be utilized to investigate further cases e.g.: (i) current braking technologies, and (ii) impact of vertical track gradient. Moreover, the formulations can be improved further by: (i) employing a Pasternak foundation for the vertical track responses, (ii) considering coupling of responses in the two directions, and (iii) inclusion of inertial effects. Nevertheless, even in its present form, the proposed approach is found to be versatile and appropriate for determination of track responses to braking loads.

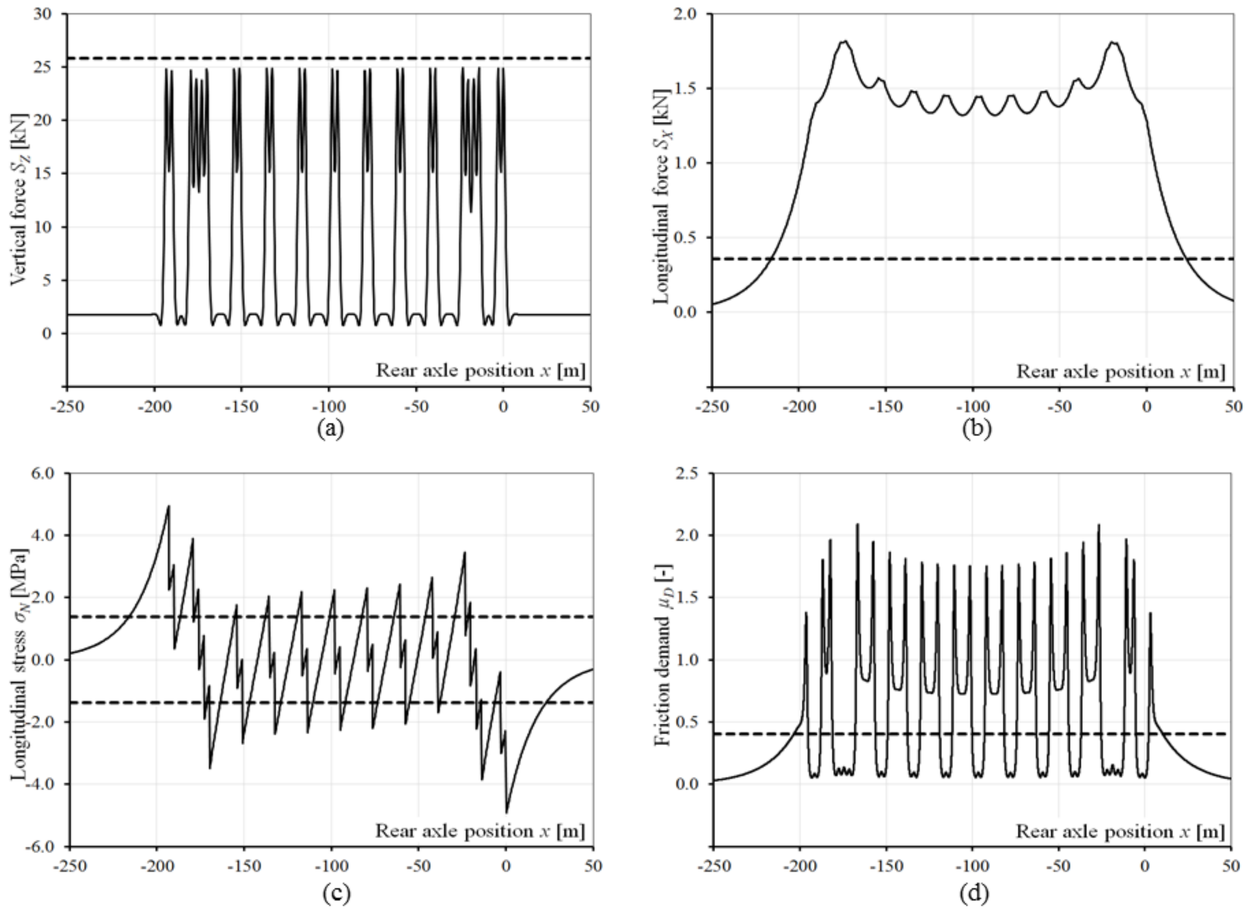

FIGURE 1: Mechanical responses at point of evaluation as a function of distance from rear axle of Thalys HST train: (a) vertical force at sleeper base, (b) longitudinal force at sleeper base, (c) longitudinal beam stress, and (d) friction demand at sleeper base. Dashed lines indicate peak values for analysis carried with a single axle.

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